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Title of the Invention: SEMICONDUCTOR VIBRATION SENSOR

[Abstract]
[Problem] To provide a semiconductor vibration sensor for simultaneously detecting acoustic vibrations and specific micro-vibrations by a single semiconductor vibration sensor.

[Means for Solving the Problem] The sensor is provided with an acoustic vibration detecting portion 11 having a vibrator film 3 consisting of a Schottky barrier junction and a buried p^+-layer 8 for efficiently propagating carriers, a micro-vibration detecting portion 12 constructed from at least one cantilever, and an element separator area 10 for electrically insulating these vibration detecting portions, wherein acoustic vibrations are converted into electric vibrations by a change of the width of a depletion layer in the vibrator film 3, and micro-vibrations are efficiently detected by the cantilever beam having a specific frequency and are converted into electric vibrations at a p-well 16, whereby the vibrations are electrically extracted.

[Scope of Claim for Patent]

[Claim 1] A semiconductor vibration sensor, characterized in being comprised of:

a semiconductor board;

a first vibration detecting portion disposed at a specific position in said semiconductor board; and

a second vibration detecting portion disposed at a position different from said specific position in said semiconductor board, having a higher frequency band than said first vibration detecting portion, and being operated on a different principle from that of said first vibration detecting portion.

[Claim 2] The semiconductor vibration sensor as recited in claim 1, characterized in that:

said first vibration detecting portion is constructed from a cantilever serving as a resonator, and piezo resistance measuring means disposed adjacent to a fixed end of said cantilever, and

said second vibration detecting portion is constructed from a vibrator film formed of a semiconductor thin film layer, and circuit parameter measuring means for measuring a change in parameters of an equivalent circuit of a depletion layer formed within said semiconductor thin film layer due to vibrations of said vibrator film.

[Claim 3] A semiconductor vibration sensor, characterized in comprising:

a vibrator film composed of a buried layer constructed from an electrically conductive material, and a semiconductor thin film layer disposed on top of said buried layer and having a higher specific resistance than said buried layer; and

circuit parameter measuring means for measuring a change in parameters of an equivalent circuit of a depletion layer formed within said semiconductor thin film layer due to vibrations of said vibrator film.

[Claim 4] The semiconductor vibration sensor as recited in claim 2 or 3, characterized in that: said depletion layer is formed within said semiconductor thin film layer by a Schottky electrode forming a Schottky barrier junction with said semiconductor thin film layer, or a semiconductor layer of an opposite-conductivity type to said semiconductor thin film layer forming a p-n junction with said semiconductor thin film layer.

[Claim 5] The semiconductor vibration sensor as recited in claim 1 or 2, characterized in further comprising: a packaging case disposed in contact with at least one principal surface of said semiconductor board, and having a sound wave inlet port at a position corresponding to said second vibration detecting portion.

[Detailed Description of the Invention]

[0001]

[Field of the Invention] The present invention relates to a semiconductor vibration sensor for detecting vibrations, and particularly to a semiconductor vibration sensor for simultaneously detecting a plurality of types of vibrations in different frequency bands and at different vibration levels.

[0002]

[Background] Semiconductor vibration sensors that have been proposed for detecting acoustic vibrations of the order of 20 Hz – 20 kHz include a capacitor-type silicon microphone having a structure such that silicon

is used as a vibrator film and a backing electrode, and silicon oxide (SiO_2) as a spacer, for measuring a change in voltage caused by a change in capacitance of the capacitor (Shin'ichi CHIBA, et al., The Proceedings of the Acoustical Society of Japan, Pages 533 – 534, September – October, 1999).

[0003] Moreover, vibration detecting sensors that have been proposed for detecting mechanical vibrations of frequency lower than acoustic vibrations include a sensor using a piezoresistive element. Specifically, when a resonator having a piezo element buried therein vibrates, the piezoresistive element deforms, which results in a change in its resistance value. By applying constant current to pass through the piezoresistive element beforehand, a change in voltage due to its varying resistance value can be read to detect mechanical vibrations.

[0004] Conventionally, the sensors of an acoustic vibration detecting type and of a mechanical vibration detecting type, the latter being for detecting vibrations having a lower frequency than the acoustic vibrations, have been separately developed as different and independent sensors; however, sometimes we need to simultaneously detect a plurality of types of vibrations in different frequency bands and at different vibration levels. For example, monitoring applications for human health or safety sometimes require an apparatus for simultaneously detecting acoustic vibrations and mechanical vibrations of frequency lower than acoustic vibrations. A human body has several types of vibrations, among which heartbeat signals have vibrations of the order of 1 Hz, and the respiratory sound of the order of

0.1 Hz. A quiver of a human body (physiological tremor) occurs not only when he/she encounters cold or terror but also in a variety of diseases or even in keeping quiet in a normal condition. Besides, there is small vibrations of a body surface generally referred to as body surface micro-vibrations. The rhythm of the body surface micro-vibrations resembles that of brain waves, and is classified into δ waves of 1 – 4Hz, θ waves of 4 – 8Hz, α waves of 8 – 13Hz, β waves of 13 – 20Hz, and ε waves of 20 – 30Hz. By relative comparison of the spectrum intensity of the body surface micro-vibrations, human psychological/mental conditions may be potentially recognized. Moreover, realization of a sensor that can simultaneously detect body surface micro-vibrations and acoustic vibrations caused by surrounding situations having a higher frequency and a higher vibration level than the body surface micro-vibrations may enable monitoring of psychological conditions of a person of interest and his/her surrounding situations. As a result, for example, it is possible to tend to the improvement of safety in public transport services by attaching the sensor to public transportation drivers.

[0005] In addition, simultaneous detection of acoustic vibrations and mechanical vibrations having a different frequency band from that of acoustic vibrations shows promise as a measure of monitoring of several kinds of equipment and instruments. For example, in an automotive engine operation monitor, micro-vibrations generated by a mechanically deteriorated portion may be measured simultaneously with an engine sound to allow more accurate monitoring of an engine, which contributes to the prevention of accidents.

[0006] For such monitoring apparatuses, it is safe to say that there is public needs for apparatuses for simultaneously detecting acoustic vibrations and mechanical vibrations in a different frequency band from that of the acoustic vibrations.

[0007]

[Problems to be Solved by the Invention] In simultaneously measuring acoustic vibrations and mechanical vibrations in a different frequency band from that of the acoustic vibrations, however, a plurality of independent vibration detecting sensors are required because there have been conventionally provided separate detecting apparatuses for that purpose. In such a case, reduction in size of a vibration detecting system is limited, which makes users feel great stress when such a system is attached to their bodies as, for example, an apparatus for monitoring human mental/physical conditions and his/her surrounding situations.

[0008] On the other hand, while acoustic vibrations and mechanical vibrations are generally different in medium that they propagate, they are common in that they are both vibrations, and therefore, it is theoretically possible to detect acoustic vibrations and mechanical vibrations with a single vibration detecting sensor. However, acoustic vibrations and mechanical vibrations are usually different in vibration level (amplitude). In a case that the amplitude of specific mechanical vibrations to be detected is small, those specific mechanical vibrations are buried under acoustic vibrations of high amplitude and having a different frequency band, which makes it difficult to detect such mechanical vibrations. Specifically, use of a single

vibration detecting sensor has a disadvantage that it gives an insufficient detection sensitivity or S/N ratio for vibrations having a specific vibration frequency to be detected.

[0009] Moreover, in a case that a plurality of kinds of vibration detecting sensors are arranged in one semiconductor board in pursuit of size reduction, an operation of one detecting apparatus may affect that of another detecting apparatus, and accordingly, size reduction of a semiconductor board is limited to a certain degree.

[0010] The present invention has been made in view of such circumstances, and its object is to provide a semiconductor vibration sensor capable of simultaneously detecting acoustic vibrations and mechanical micro-vibrations by arranging vibration detecting sensors of different frequency bands and different structures on one semiconductor board.

[0011] Another object of the present invention is to provide a small semiconductor vibration sensor by arranging vibration detecting sensors of different structures on one semiconductor board.

[0012] Still another object of the present invention is to provide a semiconductor vibration sensor that causes no mutual interference between vibration detecting sensors of different structures arranged with high density on one semiconductor board.

[0013]

[Means for Solving the Problems] A first characteristic feature of the present invention consists in a semiconductor vibration sensor comprised of a semiconductor board; and a first vibration detecting

portion and a second vibration detecting portion disposed in the semiconductor board. The "first vibration detecting portion" is disposed at a specific position in the semiconductor board. The "second vibration detecting portion" is disposed at a position in the semiconductor board different from the specific position at which the first vibration detecting portion is disposed. The "second vibration detecting portion" is a detecting portion that has a higher frequency band than the first vibration detecting portion, and has a basic structure and an operating principle different from those of the first vibration detecting portion.

[0014] According to the first characteristic feature of the present invention, the first and second vibration detecting portions with different frequency bands and different vibration levels disposed on one semiconductor board achieve improved integration, making it possible to provide a small semiconductor vibration sensor. For example, acoustic vibrations and mechanical micro-vibrations having a lower frequency and a lower vibration level than the acoustic vibrations can be detected with one semiconductor board. The first vibration detecting portion can be connected with a first amplifier suitable for properties of the first vibration detecting portion, and the second vibration detecting portion with a second amplifier suitable for properties of the second vibration detecting portion. It is preferable to configure the first and second vibration detecting portions to have a structure such that they are electrically separated from each other. A plurality of types of vibrations having different vibration levels and different frequency bands can be detected by the first and second vibration

detecting portions, and the detected vibrations can be amplified to levels equivalent to each other by individual amplifying circuits provided separately for the vibration detecting portions. Thus, a plurality of types of vibrations with different vibration levels and different frequency bands can be easily analyzed.

[0015] In the first characteristic feature of the present invention, the first vibration detecting portion may be constructed from, for example, a cantilever serving as a resonator, and piezo resistance measuring means disposed adjacent to a fixed end of the cantilever. The cantilever-form vibration sensor may be given a different resonant vibration frequency by adjusting its structure such as the length of the cantilever (resonator), and weight of a poise at the distal end thereof. Since in such a case the cantilever does not respond to vibrations having vibration frequencies except its resonant vibration frequency and frequencies therearound, a mutual effect of vibrations of the detecting devices can be eliminated by adjusting the resonant vibration frequency. For a similar reason, when vibrations desired to be detected are faint, such specific vibrations can be easily detected without being affected by noise vibrations having other vibration frequencies.

[0016] On the other hand, it is possible to construct the second vibration detecting portion from a vibrator film comprising a semiconductor thin film layer forming part of the semiconductor board, and "circuit parameter measuring means" for measuring a change in parameters of an equivalent circuit of a depletion layer formed within the semiconductor thin film due to

vibrations of the vibrator film. The depletion layer is formed within the semiconductor thin film layer from a Schottky electrode forming a Schottky barrier junction with the semiconductor thin film layer, or a semiconductor layer of an opposite-conductivity type to the semiconductor thin film layer forming a p-n junction with the semiconductor thin film layer. The "circuit parameter measuring means" may comprise an electrode of a Schottky diode or a p-n junction diode for measuring a change in impedance, a change in capacity, or a change in resistance (or conductance) of such a Schottky diode or p-n junction diode, and an operational amplifier, an I-to-V converter, etc. connected thereto. Moreover, surface wirings and the like needed to connect the electrode of the Schottky diode (or p-n junction diode) with the electronic circuits are also included in the "circuit parameter measuring means."

[0017] In the first characteristic feature of the present invention, the first vibration detecting portion measures according to its operating principle a change in piezo resistance caused by deformation of a semiconductor layer due to vibration of the cantilever serving as a resonator; on the other hand, the second vibration detecting portion measures according to its operating principle a change in parameters of an equivalent circuit of a depletion layer, so that their operating principles are different from each other.

[0018] A second characteristic feature of the present invention consists in a semiconductor vibration sensor comprising: a vibrator film; and circuit parameter measuring means for measuring a change in parameters of an electrically equivalent circuit within the vibrator

film due to vibrations of the vibrator film. The "vibrator film" is composed of a buried layer constructed from an electrically conductive material, and a semiconductor thin film layer disposed on top of the buried layer and having a higher specific resistance than the buried layer. The "circuit parameter measuring means" measures a change in parameters of an equivalent circuit of a depletion layer formed within the semiconductor thin film layer of higher specific resistance due to vibrations of the vibrator film. The "buried layer constructed from an electrically conductive material" may be comprised of a semiconductor area with high dope density of the order of 3×10^{17} cm^{-3} – 1×10^{21} cm^{-3}, and a high-melting metal, such as tungsten (W), titanium (Ti), molybdenum (Mo), and cobalt (Co), and silicides thereof (WSi_2, $TiSi_2$, $MoSi_2$, $CoSi_2$).

[0019] According to the second characteristic feature of the present invention, it is possible to convert vibrations of the vibrator film into electric signals by measuring a change in parameters of an equivalent circuit of the depletion layer. Moreover, by providing a buried layer constructed from an electrically conductive material, generation-recombination current developed within the depletion layer can be efficiently measured by the circuit parameter measuring means. The buried layer constructed from an electrically conductive material may be configured to extract current therefrom via a sinker or the like to a buried-layer extracting electrode with low resistance. The depletion layer may be formed within the semiconductor thin film layer with high specific resistance from a Schottky electrode forming a Schottky barrier junction with the

semiconductor thin film layer, or a semiconductor layer of an opposite-conductivity type to the semiconductor thin film layer forming a p-n junction with the semiconductor thin film layer, as in the first characteristic feature. The "circuit parameter measuring means" of the present invention may comprise an electrode of a Schottky diode (or p-n junction diode) needed to measure a change in impedance, a change in capacity, or a change in resistance (or conductance) of the Schottky diode (or p-n junction diode) with which such a depletion layer is formed, and electronic circuits such as an operational amplifier and an I-to-V converter connected thereto. Moreover, surface wirings and the like needed to connect the electrode of the Schottky diode (or p-n junction diode) with the electronic circuits are also included in the "circuit parameter measuring means."

[0020] In the first and second characteristic features of the present invention, there may be further provided a packaging case disposed in contact with at least one principal surface of the semiconductor board, and having a sound wave inlet port at a position corresponding to the second vibration detecting portion. By covering the semiconductor board with the packaging case, the semiconductor vibration sensor may be employed as a circuit element. The packaging case may be an integrated packaging case, or alternatively, may be constructed from a first packaging case abutted on one principal surface of the semiconductor board and a second packaging case abutted on the other principal surface of the semiconductor board and having a sound wave inlet port at a position corresponding to the second vibration detecting portion.

[0021]

[Embodiments of the Invention] Now an embodiment of the present invention will be described with reference to the accompanying drawings. In the illustration of the drawings, identical or similar portions are designated by identical or similar reference symbols. It should be noted that the drawings are all schematic, and a relationship between the thickness and width of a layer, and a proportion of the thicknesses of layers are different from those in the real world. It will also be easily recognized that the relationship or proportion of the dimensions may vary from drawing to drawing.

[0022] **(Best Embodiment)** As shown in FIG. 1, a semiconductor vibration sensor in accordance with the best embodiment of the present invention is comprised of three first vibration detecting portions 4a, 4b, 4c for detecting low-frequency vibrations, and a vibrator film 3 serving as a second vibration detecting portion. The second vibration detecting portion is for detecting acoustic vibrations, and its frequency band is higher than any one of the three first vibration detecting portions 4a, 4b, 4c. The second vibration detecting portion has a basic structure and an operating principle different from those of any one of the three first vibration detecting portions 4a, 4b, 4c. The three first vibration detecting portions 4a, 4b, 4c having resonant frequencies different from one another are each a sensor for detecting vibrations of lower frequency than acoustic vibrations, and they have a common basic structure and operating principle. The three first vibration detecting portions (micro-vibration detecting portions) are comprised of resonators constructed from cantilevers 4a,

4b, 4c, respectively. The three cantilevers 4a, 4b, 4c are provided for detecting micro-vibrations of different frequency bands by giving the cantilevers 4a, 4b, 4c different dimensions to have different resonant vibration frequencies. Therefore, the number of cantilevers is not limited to three and is determined by the frequency unique to micro-vibrations desired to be detected.

[0023] The semiconductor vibration sensor in accordance with an embodiment of the present invention is fabricated on a semiconductor board, for example, an n-type silicon (Si) substrate 5 having a (100) plane. A vibrator film 3, which serves as the second vibration detecting portion, is disposed in a central portion of the Si substrate 5. An I-to-V converter 7 is disposed on the left of the vibrator film 3. The vibrator film 3 is connected with the I-to-V converter 7 via a buried p^+-layer 8 and a buried-layer extracting electrode 9. Moreover, the vibrator film 3 is also electrically connected with the I-to-V converter 7 on the surface of the Si substrate 5. Two bonding pads 2e, 2f for external output are disposed on the left of the I-to-V converter 7 in proximity to the periphery of the Si substrate (chip) 5. The I-to-V converter 7 is connected with the two bonding pads 2e, 2f via aluminum wirings. An area including the vibrator film 3 and I-to-V converter 7 is surrounded by an element separator area 10 embedded within the Si substrate 5.

[0024] Moreover, by insulating the acoustic vibration detecting portion from the micro-vibration detecting portion by the element separator area, carriers generated in one semiconductor vibration sensor can be prevented from being introduced into the other

semiconductor vibration sensor.

[0025] A "constant current source and amplifying circuit" 6a is disposed above the second vibration detecting portion (vibrator film) 3 to be connected to piezo resistance measuring means for the first vibration detecting portion 4a. The first vibration detecting portion (cantilever) 4a is disposed on the right of the constant current source and amplifying circuit 6a and at an upper right corner of the Si substrate 5. The constant current source and amplifying circuit 6a and the cantilever 4a are electrically connected with each other via two aluminum wirings. Four bonding pads 2a, 2b, 2c, 2d are longitudinally disposed on the left of the constant current source and amplifying circuit 6a and along the left edge of the Si substrate 5. Of these, the two upper bonding pads 2a, 2b are electrically connected with the constant current source and amplifying circuit 6a to serve as voltage output terminals. The two lower bonding pads 2c, 2d are electrically connected with the constant current source and amplifying circuit 6a to serve as power source terminals for the constant current source and amplifying circuit 6a.

[0026] The top plan view of FIG. 1 shows a "constant current source and amplifying circuit" 6b also disposed below the vibrator film 3, and connected to the piezo resistance measuring means for the first vibration detecting portion 4b. The first vibration detecting portions (cantilevers) 4b, 4c are disposed on the right of the vibrator film 3 and below the first vibration detecting portion (cantilever) 4a. The constant current source and amplifying circuit 6b is electrically connected with the cantilever 4b via two aluminum wirings

therebetween. Two bonding pads 2g, 2h are disposed on the left of the constant current source and amplifying circuit 6b in proximity to the lower left chip end surface of the Si substrate 5. The bonding pads 2g, 2h in proximity to the lower left chip end surface serve as voltage output terminals, and are electrically connected with the constant current source and amplifying circuit 6b via aluminum wirings. Two bonding pads 2i, 2j are disposed below the constant current source and amplifying circuit 6b in proximity to the periphery of the Si substrate 5, and are electrically connected with the constant current source and amplifying circuit 6b via aluminum wirings to serve as power source terminals. Moreover, a "constant current source and amplifying circuit" 6c is disposed below the constant current source and amplifying circuit 6b and on the right of the vibrator film 3, and is connected to the piezo resistance measuring means for the first vibration detecting portion 4c. Two bonding pads 2k, 2l are disposed on the right of the constant current source and amplifying circuit 6c in proximity to the lower right chip end surface of the Si substrate 5, and are electrically connected thereto via aluminum wirings to serve as voltage output terminals. For power source terminals for the constant current source and amplifying circuit 6c, the bonding pads 2i, 2j are shared with the power source terminals for the constant current source and amplifying circuit 6b, and the constant current power source and amplifying circuit 6c is electrically connected with the bonding pads 2i, 2j via aluminum wirings.

[0027] FIG. 2 is a partial cross-sectional view of the semiconductor vibration sensor in accordance with the

embodiment of the present invention shown in FIG. 1 as viewed in an A-A direction. As shown in FIG. 2, the semiconductor vibration sensor in accordance with the embodiment of the present invention is comprised of a semiconductor board (Si substrate) 5; and a first vibration detecting portion (micro-vibration detecting portion) 12 and a second vibration detecting portion (acoustic vibration detecting portion) 11 disposed on the semiconductor board (Si substrate) 5. The first vibration detecting portion (micro-vibration detecting portion) 12 is disposed at the right of the semiconductor board 5. The second vibration detecting portion (acoustic vibration detecting portion) 11 is disposed at a position in the semiconductor board 5 different from that at which the first vibration detecting portion 12 is disposed. The Si substrate 5 is provided in its lower end region with two recesses. The Si substrate 5 has a thick structure at its left-end, central and right-end portions, with thin portions forming bottoms of the recesses disposed therebetween. Side surfaces of the two recesses are exposed (111) planes with respect to the (100) plane of the substrate surface, and intersect with the (100) plane at an angle of 54.74°. The thin portion forming the bottom of the left recess is provided for the need of constituting the second vibration detecting portion (acoustic vibration detecting portion) 11 for detecting acoustic vibrations. The thin portion at the bottom of the right recess is provided for causing stress due to vibrations to concentrically apply to this region in order to constitute the first vibration detecting portion (micro-vibration detecting portion) 12 for detecting mechanical micro-vibrations. Details of the

second vibration detecting portion (acoustic vibration detecting portion) 11 and first vibration detecting portion (micro-vibration detecting portion) 12 in the cross-sectional view of FIG. 2 will be discussed later.

[0028] FIG. 3 is a cross-sectional view of a package of the semiconductor vibration sensor in accordance with the embodiment of the present invention. A first packaging case 24 abutted on one principal surface (front surface) of the semiconductor board 5 is provided for the purpose of protecting the front surface of the semiconductor vibration sensor. The first packaging case 24 is connected with the semiconductor vibration sensor at a portion between the bonding pad 2 and buried-layer extracting electrode 9 and at a portion on the right of the cantilever, so that it covers the semiconductor vibration sensor to envelop the acoustic vibration detecting portion and micro-vibration detecting portion within the package (In FIG. 3, the bonding pads 2a, 2b, 2c, ... shown in FIG. 1 are collectively designated as "bonding pad 2"). The bonding pad 2 is disposed outside the packaging case 24 because of the need for output to the outside using a lead 26. A lower portion (the other principal surface) of the semiconductor vibration sensor is protected by a second packaging case 23, which is coupled to the lower portion of the semiconductor vibration sensor except the cantilever. To detect acoustic vibrations at the vibrator film 3, the second packaging case 23 is provided with a sound wave inlet port 25 at a position corresponding to the second vibration detecting portion 1 (a position below the vibrator film 3). The first packaging case 24 may be constructed integrally with the second packaging case 23

so that part of them is abutted on one principal surface, that is, either the front surface or rear surface, of the semiconductor board 5 (which of the front surface or rear surface is called "one principal surface" or "the other principal surface" is merely an issue of definition).

[0029] **[Acoustic vibration detecting portion (Second vibration detecting portion)]** Next, returning to the cross-sectional view of FIG. 2, a structure of the acoustic vibration detecting portion (second vibration detecting portion) 11 will be described. In the embodiment of the present invention shown in FIG. 2, the second vibration detecting portion (acoustic vibration detecting portion) 11 is comprised of the vibrator film 3; and circuit parameter measuring means (15, 9, 13) for measuring a change in parameters of an electrically equivalent circuit within the vibrator film 3 due to vibration of the vibrator film 3. Of the lower end portion of the Si substrate 5, the vibrator film 3 is disposed in a thin film part constituting the bottom of the left recess. The vibrator film 3 forms a three-layer structure, which is composed of a buried layer 8 constructed from an electrically conductive material, a semiconductor thin film layer disposed on top of the buried layer 8 and having a higher specific resistance than the buried layer 8, and a Schottky electrode 13 for creating a depletion layer 14 in the higher-specific-resistance semiconductor thin film layer. The "buried layer 8 constructed from an electrically conductive material" at the lowest level is a semiconductor area (buried p^+-layer) of p-type high doping density of the order of 3×10^{17} cm^{-3} – 8×10^{19} cm^{-3}. Representing it with specific resistance, it is of the order of 0.014 $\Omega\cdot$cm –

$0.013\ \Omega\cdot cm$. On top of the buried p^+-layer 8 is formed a p-type layer having a lower doping density than the buried p^+-layer 8, for example, of the order of $5\times10^{12}\ cm^{-3}$ – $1\times10^{14}\ cm^{-3}$. The specific resistance of such a p-type layer is of the order of $2.7\ k\Omega\cdot cm$ – $140\ \Omega\cdot cm$. The higher specific resistance (lower doping density) of the p-type layer is used for the purpose of expanding the width of the depletion layer of the Schottky barrier junction. The buried layer having a lower specific resistance allows carriers generated in the depletion layer to be efficiently conducted to the I-to-V converter.

[0030] The p-type layer is also provided near its left edge with a p^+-sinker 15 having a high doping density similar to that of the buried p^+-layer 8 to form part of the circuit parameter measuring means (15, 9, 13). A position to dispose the p^+-sinker 15 lies at the left of the vibrator film 3, which position corresponds to a portion above a portion where the (111) plane at the bottom of the Si substrate 5 is exposed. The Schottky electrode 13 is disposed on top of the p-type layer and on the front surface of the Si substrate 5. The Schottky electrode 13 is desirably made from a metal of high specific gravity. This is for efficiently detecting acoustic vibrations. In the embodiment of the present invention, gold (Au) is employed; however, it will be easily recognized that the material for the Schottky electrode 13 is not limited thereto. Since an area under the Schottky electrode 13 is the p-type layer having a lower doping density as described above, the Schottky electrode 13 and underlying p-type layer together form a Schottky barrier junction rather than an ohmic junction. Thus, the depletion layer 14 is formed in the underlying

p-type layer below the Schottky electrode 13. By setting the doping density of the p-type layer for a value of the order of 5×10^{12} cm^{-3} – 1×10^{14} cm^{-3} or lower, the depletion layer develops only with a diffusion potential (built-in potential). It is thus possible to operate the acoustic vibration detecting portion (second vibration detecting portion) 11 without the need for providing a bias power source for the Schottky barrier junction. It should be noted that it is also possible to form a depletion layer with a p-n junction by forming an n-type layer on top of the p-type layer, instead of the Schottky electrode 13. In this case, an ohmic electrode is formed on the surface of the n-type layer.

[0031] The element separator area 10 is disposed along opposite edges of the buried p^+-layer 8 and p-type layer (depletion layer 14). The element separator area 10 is formed by embedding an element separator insulating film such as an oxide film in a U-shaped gutter portion (trench) having such a depth that it passes through the buried p^+-layer from the front surface of the Si substrate 5. Moreover, as shown in FIG. 1, the element separator area 10 is formed in an angular ring to surround the Schottky electrode 13. Furthermore, the buried-layer extracting electrode 9 is disposed to be contiguous with the p^+-sinker 15.

[0032] FIG. 5 is a perspective view of the vicinity of the vibrator film portion in the acoustic vibration detecting portion 11, showing the dimensions of the vibrator film 3. The vibrator film 3 has a laminar rectangular parallelepiped structure of 3 mm in length, 3 mm in width, and 6 μm in height. Referring to FIGS. 2 and 5, acoustic vibrations entering the vibrator film 3

at the acoustic vibration detecting portion 11 cause the vibrator film 3 to physically vibrate. The vibrations of the vibrator film 3 cause a change in physical parameters of the semiconductor area constituting the depletion layer 14, resulting in variation in parameters of an electrically equivalent circuit, such as depletion layer capacity or junction resistance. Moreover, since the vibrations also generate "generation-recombination current" in the depletion layer, electric current caused by the "generation-recombination current" flows through the depletion layer 14. This is combined with the change in parameters of an electrically equivalent circuit described above to convert physical vibrations into electric vibrations as a result. The electric current is carried through the buried p^+-layer 8 and p^+-sinker 15 to the buried-layer extracting electrode 9, and ultimately to the I-to-V converter 7. The I-to-V converter 7 converts the electric current output into voltage output, which is output to the outside via the bonding pads 2e, 2f connected to the I-to-V converter 7. It should be noted that voltage of the buried-layer extracting electrode 9 that is in ohmically contact with the p^+-sinker 15 is applied to the buried p^+-layer 8 via the p^+-sinker 15. Therefore, desired voltage can be applied between the Schottky electrode 13 and buried p^+-layer 8. Specifically, the variation of the parameters of an electrically equivalent circuit can be enhanced by making an underlying portion of the Schottky electrode 13 from a p-type layer of lower doping density to form an expanded depletion layer 14 by the p-type layer. Furthermore, since the buried p^+-layer 8 having a large area is provided below the p-type layer, carriers generated in

the depletion layer 14 can be efficiently extracted and carried to the I-to-V converter 7.

[0033] FIG. 7 shows a simplified form of an electrically equivalent circuit of the acoustic vibration detecting portion 11. Although a precise form of an equivalent circuit of a Schottky diode is extremely complex, FIG. 7 is illustrated taking account of only depletion layer capacity C_j, junction resistance R_j, generation-recombination current igr due to vibrations, and series resistance Rs such as contact resistance and parasitic resistance. Specifically, the depletion layer 14 shown in FIGS. 2 and 5 has therein depletion layer capacity C_j and junction resistance R_j, and develops generation-recombination current igr due to vibrations, and therefore, the portion of the depletion layer 14 can be expressed by a parallel connection circuit of these C_j, R_j and igr. Moreover, series resistance Rs components other than the depletion layer 14 are approximated to be connected in series to the parallel circuit representing the depletion layer 14. Although a precise form of an equivalent circuit of a Schottky diode is constructed as a complex series-parallel combination circuit having a plurality of additional C and R components, it can be expressed in first-order approximation as shown in FIG. 7. (It should be noted that while a precise form of an equivalent circuit of a p-n junction diode is also extremely complex, it can be expressed by a parallel connection of C_j, R_j and igr, and a series resistance Rs connected in series to the parallel circuit in a simplified representation, as in FIG. 7.) Opposite edges of the equivalent circuit 27 of the acoustic sensor (Schottky diode) indicated by a dashed line in FIG. 7 are

connected to two input terminals of an operational amplifier circuit 30 (which corresponds to the I-to-V converter 7 in FIG. 1). The input impedance between the two input terminals of the operational amplifier circuit 30 is approximated as infinity. A feedback resistance Rf is connected between one input terminal and an output terminal of the operational amplifier circuit 30. Output voltage 29 is output to the outside by such an amplifying circuit. Therefore, particularly, a value Vs of the output voltage 29 is given by the following equation:

$$Vs = Rf\ (V0s\ (dC_j\ /\ dt) + V0s\ /\ (Rs + R_j) + igr), \quad \ldots\ldots (1)$$

where input voltage between the two input terminals of the operational amplifier circuit 30 is represented as V0s. In other words, electric current caused by carriers generated in the depletion layer 14 is converted into output voltage Vs by the operational amplifier circuit 30.

[0034] The "circuit parameter measuring means" of the present invention comprises the p^{+}-sinker 15 for a Schottky diode (or p-n junction diode) for measuring a change in impedance, a change in capacity, or a change in resistance (or conductance) of the Schottky diode (or p-n junction diode), and an electrode, such as the Schottky electrode 13 or buried-layer extracting electrode 9, and in addition, surface wirings (not shown) connected thereto. Moreover, the operational amplifier circuit 30 connected via the surface wirings is also included in the "circuit parameter measuring means" of the present invention.

[0035] **[Micro-vibration detecting portion (First vibration detecting portion)]** Next, a structure of the micro-vibration detecting portion (first vibration

detecting portion) 12 in the vicinity of the right recess shown in the cross-sectional view of FIG. 2 will be described. In the cross-sectional view shown in FIG. 2, the Si substrate 5, in proximity to its right edge, is expressed as if it were physically divided into two regions by a V-shaped gutter portion. In actuality, this portion is continuous behind the drawing plane, as can be seen from the top plan view of FIG. 1. The V-shaped gutter portion shown in proximity to the right edge is a gutter for forming a free end of the cantilever 4b. Of the two physically separated regions in the cross-sectional view shown in FIG. 2, the right region has no special structure, so that its explanation will be omitted; the following description will address the left region.

[0036] The Si substrate 5 in the vicinity of the thin region of the Si substrate 5 forming the bottom of the right recess has its inside a p-well 16 forming part of the piezo resistance measuring means. The p-well 16 is provided in proximity to its opposite edges with contact areas 17a, 17b having a higher doping density than the p-well 16. On top of the contact areas 17a, 17b and on the Si substrate 5 are disposed piezoelectrodes 19, 20, respectively. The p-well 16, contact areas 17a, 17b, and piezoelectrodes 19, 20 constitute the piezo resistance measuring means. The whole surface of the Si substrate 5 in areas other than the aforementioned Schottky electrode 13, buried-layer extracting electrode 9, and piezoelectrodes 19, 20 is covered with a passivation film 18.

[0037] The cantilever 4b shown in FIG. 2 serves as a resonator that vibrates in response to mechanical micro-

vibrations from the outside. The thin portion of the Si substrate 5, that is, the fixed end of the resonator (cantilever) 4b concentrically experiences stress due to vibrations of the resonator (cantilever) 4b. The p-well 16 is thus subjected to intense pressure, which results in a change in its electric resistance value. By applying constant current through the piezoelectrodes 19, 20 to the p-well 16, mechanical vibrations can be converted into electric vibrations, represented as variation of voltage. While not explicitly shown in FIG. 2, the piezoelectrodes 19, 20 are electrically connected to the constant current source and amplifying circuit 6b shown in FIG. 1, and the obtained electric vibrations are output to the outside through the bonding pads 2g, 2h. The cantilevers 4a and 4c shown in FIG. 1 are similar to that, though their cross-sectional views are omitted.

[0038] FIG. 4 is a perspective view showing a structure of the cantilever 4 (the cantilevers 4a, 4b, 4c are collectively designated as "cantilever 4" here unless explicitly stated otherwise). The cantilever 4 has a structure such that a rectangular parallelepiped having 'b' in length, 'l' in width, and 'h' in height, and serving as a piezo resistance portion, is combined with a rectangular parallelepiped having 'y' in length, 'x' in width, and 'h' in height, and serving as a poise. The cantilever 4 has a resonant vibration frequency f0 according to its structure, and its resonant vibration frequency is approximated by an equation:

$$f_0 = \omega_0 / 2\pi = (1 / 2\pi)(3EJ / ml^3)^{1/2}, \quad \ldots\ldots (2)$$

wherein m represents a mass of the poise of the cantilever, E represents a Young's modulus, and J =

$bh^3/12$. Since the density of Si is 2.3 g/cm^3 and the Young's modulus is 13.1 N/m^2, when it is assumed that $h=h'=28$ μm, $b=1$ mm, $l=3.5$ mm, $x=3.5$ mm, and $y=7$ mm in FIG. 4, the cantilever has a resonant vibration frequency $f_0=80$ Hz from EQ. (2).

[0039] FIG. 6 shows an electrically equivalent circuit of a portion consisting of the cantilever 4b and constant current source and amplifying circuit 6b. A p-type piezo resistance layer Rp by the p-well 16 is connected with a constant current circuit ic in the constant current source and amplifying circuit 6b, which is connected to an amplifier A. Electric vibrations amplified at the amplifier A is output to the outside as output voltage 28. A specific value of the output voltage 28 is given by:

$$Vs = A \cdot Rp \cdot ic, \qquad \ldots\ldots (3)$$

where A designates an amplification degree of the amplifier. Likewise, an electrically equivalent circuit of a portion consisting of the cantilever 4a and constant current source and amplifying circuit 6a, and that of a portion consisting of the cantilever 4c and constant current source and amplifying circuit 6c can give output voltage as given by EQ. (3).

[0040] FIGS. 8 and 9 show schematic diagrams of a monitoring system for human mental/physical conditions and surrounding situations using the semiconductor vibration sensor in accordance with the embodiment of the present invention. FIG. 8 is directed to a an acoustic vibration and body surface micro-vibration detecting system carried by a person of interest for measurement. Vibrations detected by the acoustic vibration detecting portion 11, micro-vibration detecting portion 12a, micro-

vibration detecting portion 12b, and micro-vibration detecting portion 12c are amplified by amplifiers A1, A2, A3, A4, respectively, to have similar intensities. This is because the intensity of vibrations detected at the detecting portions is different according to a type of vibrations, and the vibrations should be leveled to have similar intensities before combination at an adder 31 for facilitating subsequent analysis. The body surface micro-vibrations have a significant lower vibration level than acoustic vibrations. Thereafter, the vibrations added at the adder 31 pass through a modulator 32, and are transmitted from an antenna 33.

[0041] FIG. 9 is directed to a data analysis center for analyzing surrounding situations and mental/psychological conditions of a person of interest for measurement. First, radio waves transmitted from the detecting system carried by the person of interest for measurement are received at a receiver section 34. Then, the received radio waves are amplified at an amplifier A5, and subjected to Fourier transform at an FFT (high speed Fourier transformer). Then, their frequency and its spectrum are analyzed at a frequency spectrum analyzer 37 for detecting α or β waves. At that time, data communication is made with a knowledge database 38 for spectrum analysis. Thereafter, surrounding situations and mental/psychological conditions of the person of interest for measurement from the analysis are displayed on a display 39.

[0042] Now a method of making the semiconductor vibration sensor in accordance with the embodiment of the present invention will be described with reference to stepwise cross-sectional views shown in FIGS. 10, 11 and

12.

[0043] (A) First, an n-type Si substrate 5 having a (100) plane is prepared, a resist 40 is coated over the Si substrate 5 on the (100) plane by a spin coating technique or the like, and the resist 40 is formed using photolithography to have a pattern with an opening in an area where a buried p^+-layer 8 is to be formed. The resist 40 is used as a mask to apply ion implantation to the Si substrate 5 in a direction perpendicular to the (100) plane with p-type dopant ions such as boron ions ($^{11}B^+$) at a high dose of the order of 3×10^{15} cm^{-2} – 8×10^{16} cm^{-2}. When ion implantation is applied at high energy of 1 MeV or higher, a metal film may be deposited under the resist 40 by a vapor deposition technique or the like, and ion implantation may be applied with a two-layer mask of a resist/metal film. For example, ion implantation with $^{11}B^+$ at 2 MeV results in a projection range of the order of 2.8 μm, and ion implantation with $^{11}B^+$ at 3 MeV results in a projection range of the order of 3.9 μm. Thereafter, by heat treatment for activation, the buried p^+-layer 8 is formed at a position of the desired projection range, as shown in FIG. 10(a). Next, the resist 40 is removed (or in a case of the two-layer mask of the resist/metal film, the underlying metal film is removed as well), and a diffusion mask is formed for forming a p-well layer 16 and a p-type layer on top of the buried p^+-layer, as shown in FIG. 10(b). A resist 41 is coated over the Si substrate 5 using the spin coating technique, and the resist 41 is formed using photolithography to have a pattern with openings in areas where the p-well layer 16 and the p-type layer on top of the buried p^+-layer are to be formed. The resist 41 is

used as a mask to implant p-type dopant ions such as $^{11}B^+$ into the Si substrate 5 in a direction perpendicular to the (100) plane of the Si substrate 5 at a relatively low dose of the order of 3×10^{13} cm^{-2} – 8×10^{14} cm^{-2}. The acceleration energy for the p-type dopant ions in this case may be of the order of 50 – 150 keV. Thereafter, the resist 41 is removed and heat treatment is applied at, for example, 1150 °C for about 1 – 3 hours, whereby the buried p^+-layer 8, p-well layer 16, and the p-type layer on top of the buried p^+-layer 8 can be formed, as shown in FIG. 10(b). At this step, the p-well layer 16 need not reach the buried p^+-layer 8, as shown in FIG. 10(b). It should be noted that the buried p^+-layer 8 may be formed by forming a p^+-diffusion layer in the Si substrate 5 by selective diffusion, and then, depositing an n-type epitaxially grown layer over the p^+-diffusion layer.

[0044] (B) Next, a resist film is formed over the Si substrate 5 using the spin coating technique, and a resist 42 is formed using photolithography to have a pattern with openings in areas where a p^+-sinker 15, a contact area 17a and a contact area 17b are to be formed. The resist 42 is used as a mask to implant p-type dopant ions such as $^{11}B^+$ or $^{49}BF_2^+$ into the Si substrate 5 in a direction perpendicular to the (100) plane at a high dose of the order of 3×10^{15} cm^{-2} – 1×10^{16} cm^{-2}. In this case, the acceleration may be made with low energy of the order of 30 – 80 keV. Thereafter, the resist 42 is removed and heat treatment is applied at a certain temperature and for a certain time, for example, at 1150°C for about 7 – 10 hours, whereby the p^+-sinker 15, contact area 17a and contact area 17b are formed as shown in FIG. 10(c).

While the p-well layer 16 need not reach the buried p^+-layer 8 in FIG. 10(b), it now reaches the buried p^+-layer 8.

[0045] (C) Next, a silicon dioxide (SiO_2) film 43 is formed over the surface of the Si substrate 5 by a thermal oxidation technique or the like. Moreover, a silicon nitride (Si_3N_4) film 43 is formed over the silicon dioxide film 43 by a CVD technique. Next, anisotropic etching such as reactive ion etching (RIE) is applied to form a U-shaped gutter portion (trench), as shown in FIG. 10(d). Then, as shown in FIG. 10(e), the silicon nitride (Si_3N_4) film 43 is used as a non-oxidizable mask, and thermal oxidation is applied to selectively embed SiO_2 into the U-shaped trench, thereby forming an element separator area 10. After completion of selective oxidation, the silicon nitride film 43 used as non-oxidizable mask is removed by an etchant such as hot phosphoric acid. It should be noted that a method, other than selective oxidation using the silicon nitride film 43, may be used to selectively embed SiO_2 into the U-shaped trench, such as a method involving depositing it by the CVD method all over the surface, and applying a planarization step, for example, etching back or chemical-mechanical polishing (CMP). It should be also noted that the element separator area 10 is formed for the purpose of insulating between the plurality of semiconductor vibration sensors, and therefore, it is possible to use a material other than SiO_2 in the element separator area 10 insofar as it attains the purpose.

[0046] (D) Next, a resist film is formed over the rear surface of the Si substrate 5 by the spin coating technique, and a resist 45 is formed using

photolithography to have a pattern with an opening in an area where a vibrator film 3 is to be formed. Thereafter, the resist 45 is used as an etching mask to apply anisotropic etching with an etchant, such as aqueous ethylenediamine ($H_2N \cdot CH_2CH_2NH_2$) or aqueous potassium hydroxide (KOH), to remove the Si portion under the buried p^+-layer 8 from the rear surface of the Si substrate 5 until the buried p^+-layer 8 is exposed. As a result, the vibrator film 3 in the acoustic vibration portion 11 is formed, as shown in FIG. 11(a). The resist 45 is then removed.

[0047] (E) Next, a resist film 46 is formed over the rear surface of the Si substrate 5 by the spin coating technique, and the resist 46 is formed using photolithography to have a pattern with openings in areas where a portion below the well 16 and the free vibrating end of the cantilever are to be formed. Then, the resist 46 is used as an etching mask to apply anisotropic etching with an etchant such as aqueous ethylenediamine or aqueous potassium hydroxide. As a result, the portion in the Si substrate 5 below the p-well 16 and the vicinity of the free vibrating end of the cantilever in the Si substrate 5 are selectively removed, as shown in FIG. 11(b). Since the depth of etching in FIG. 11(b) is different from that in FIG. 11(a), this step is performed separately from the etching for forming the vibrator film 3.

[0048] (F) Next, a resist film is formed over the front surface of the Si substrate 5 by the spin coating technique, and a resist 47 is formed using photolithography to have a pattern with an opening in an area where the free end is to be formed. Then, the

resist 47 is used as an etching mask to apply anisotropic etching, and form the free vibrating end of the cantilever, as shown in FIG. 11(c). At this step, a resist 48 is formed beforehand over the whole rear surface of the Si substrate 5 by the spin coating technique to prevent the rear surface of the Si substrate 5 from being etched. After completion of the anisotropic etching process, the resist 47 used as etching mask is removed.

[0049] (G) Next, a resist film is formed over the front surface of the Si substrate 5 by the spin coating technique, and a resist 49 is formed using photolithography to have a pattern with respective openings in areas where a buried-layer extracting electrode 9, a piezoelectrode 20, and a piezoelectrode 19 are to be formed. Thereafter, the resist 49 is used as an etching mask to apply selective etching to the silicon dioxide film 43, as shown in FIG. 11(d), and form respective contact holes for the buried-layer extracting electrode 9, piezoelectrode 20, and piezoelectrode 19. At this step, the resist 48 used at the preceding step is left unremoved beforehand to prevent the rear surface of the Si substrate 5 from being etched.

[0050] (H) Next, by means of the contact holes formed through the silicon dioxide film 43, a metal film, such as aluminum (Al) or aluminum alloy (Al-Si, Al-Cu-Si), serving as electrodes is deposited using a vapor deposition or sputtering technique. As shown in FIG. 11(e), the metal film is patterned using photolithography and RIE to form the buried-layer extracting electrode 9, piezoelectrode 20, and piezoelectrode 19. Then, to realize an ohmic junction, sintering is applied in an

atmosphere of H_2 or the like at an temperature of the order of 400°C - 450°C.

[0051] (I) Next, a resist film is formed over the whole front surface of the Si substrate 5 by the spin coating technique, and a resist 50 is formed using photolithography to have a pattern with an opening in an area where a Schottky electrode 13 is to be formed. The resist 50 is then used as an etching mask to apply selective etching to the silicon dioxide film 43 to cause the surface of the Si substrate 5 to be exposed in an area where a Schottky electrode 13 is to be formed, as shown in FIG. 12(a). Next, the resist 50 used as an etching mask is now used as a lift-off mask to deposit the Schottky electrode metal, such as gold, by the vapor deposition or sputtering technique. The resist 50 and metal adhered to the resist 50 are then removed, whereby the Schottky electrode 13 is patterned, as shown in FIG. 12(b). After these steps, the semiconductor vibration sensor as shown in FIG. 1 can be made.

[0052] **(Variation 1)** A semiconductor vibration sensor in accordance with Variation 1 of the embodiment of the present invention is shown in FIG. 13, where circuit elements required in the constant current source and amplifying circuit portion are integrated on the surface of the poise of the cantilever that constitutes the micro-vibration detecting portion (first vibration detecting portion) 9. By thus integrating the constant current source and amplifying circuit portion on the surface of the poise of the cantilever, the size of the semiconductor vibration sensor can be further reduced. While the structure of a MOS integrated circuit comprised of a MOS transistor is illustrated in FIG. 13, it will be

easily recognized that this is provided merely by way of example for aiding understanding, and other semiconductor integrated circuits, such as a bipolar junction transistor (BJT)-based integrated circuit or static induction transistor (SIT)-based integrated circuit, may be employed insofar as the circuit constitutes the constant current source and amplifying circuit portion.

[0053] **(Variation 2)** A semiconductor vibration sensor in accordance with Variation 2 of the embodiment of the present invention has a boat-shaped pit 54 formed under the cantilever 52 in a micro-vibration detecting portion (first vibration detecting portion) 55, as shown in FIG. 14. Moreover, the cantilever 52 is covered in its lower portion with the Si substrate 5. The positioning and characteristic features of other portions in the cross-sectional view shown in FIG. 14, for example, those of the acoustic vibration detecting portion (second vibration detecting portion) 11, piezoelectrodes 19, 20 in the micro-vibration detecting portion 55, and p-well 53, are generally similar to those in the semiconductor vibration sensor shown in FIG. 2.

[0054] In the semiconductor vibration sensor according to Variation 2 of the embodiment of the present invention, the cantilever 52 is covered in its lower portion with the Si substrate 5, whereby the cantilever 52 is protected by the Si substrate 5.

[0055] The method of making the semiconductor vibration sensor according to Variation 2 of the embodiment of the present invention is basically the same as the method of making the semiconductor vibration sensor in accordance with the embodiment of the present invention shown in FIGS. 1 and 2. However, to form the

boat-shaped pit 54, the method is characterized in that the upper portion of the semiconductor vibration sensor is fabricated separately from the lower portion, and thereafter, they are bonded together by a silicon direct bonding (SDB) technique. At that time, the surfaces to be bonded must be machined to be extremely smooth. Moreover, since the bonding process must be conducted at a temperature as high as about 1000°C, the process must be completed before forming metal electrodes and metal wirings. It should be noted that the method of making the semiconductor vibration sensor according to Variation 2 of the embodiment of the present invention is not limited thereto, and other methods may be employed insofar as the pit 54 can be effectively made.

[0056] The semiconductor vibration sensor according to Variation 2 of the embodiment of the present invention is characterized in that, in addition to the characteristic features similar to those of the semiconductor vibration sensor in the embodiment of the present invention shown in FIGS. 1 and 2, it can realize a semiconductor vibration sensor highly resistant to impact by employing the aforementioned structure.

[0057] FIG. 15 is a cross-sectional view of a package for the semiconductor vibration sensor according to Variation 2 of the embodiment of the present invention. A first packaging case 57 is abutted on one principal surface (front surface) of the semiconductor board, and a second packaging case 56 is abutted on the other principal surface (rear surface) of the semiconductor board. A difference from the package of the semiconductor vibration sensor in accordance with the embodiment of the present invention shown in FIGS. 1 and

2 is that the semiconductor vibration sensor contact area of the second packaging case 56 in contact with the lower portion of the semiconductor vibration sensor is larger as compared with the embodiment of the present invention shown in FIGS. 1 and 2. The portion of the second packaging case 56 under the micro-vibration detecting portion also serves as a receiving portion for micro-vibrations, so that it is possible to efficiently detect micro-vibrations by bringing a larger area of such a portion into contact with the rear surface of the micro-vibration detecting portion. Features, such as the sound wave inlet port 25 provided for introducing acoustic vibrations to the vibrator film 3, are similar to the package in accordance with the embodiment of the present invention shown in FIGS. 1 and 2.

[0058] **(Other Embodiments)** The present invention has been described above with reference to the best embodiment; however, the description and drawings forming part of this disclosure should not be construed as limiting the invention. Various alternative embodiments, practical examples and operation techniques are apparent to those skilled in the art from this disclosure.

[0059] In the embodiment of the present invention, and Variations 1 and 2 thereof described above, it is possible to implement the semiconductor vibration sensor in accordance with the embodiment of the present invention, and Variations 1 and 2 thereof by substituting a p-type Si substrate for the n-type Si substrate 5, an n^+-buried layer for the p^+-buried layer 8, an n^+-sinker for the p^+-sinker 15, and n-well for the p-well 16.

[0060] Moreover, the process of making the semiconductor vibration sensor shown in FIGS. 10 – 12 is

provided merely by way of example. For example, it is possible to omit the process of forming the p^+-buried layer 8 at step (A) shown in FIG. 10(a), and form the p^+-buried layer 8 at a later step. Specifically, after completing the anisotropic etching process at step (D) shown in FIG. 11(a), p-type dopant ions may be selectively implanted to the bottom of the recess formed by anisotropic etching, that is, to the rear surface of the vibrator film 3. In this case, the resist 45 used as etching mask for the anisotropic etching may be left unremoved, and is used as an ion implantation mask to selectively implant the p-type dopant ions. After the ion implantation, the p^+-buried layer 8 is formed by removing the ion implantation mask 45, and applying heat treatment for a certain time to cause thermal diffusion. Likewise, in the process of making the semiconductor vibration sensor in accordance with Variations 1 and 2, it is possible to conduct the process of forming the p^+-buried layer 8 after the anisotropic etching process at step (D).

[0061] Moreover, in the embodiment of the present invention, and Variations 1 and 2 thereof, the first vibration detecting portion is described as a micro-vibration detecting portion for measuring a change in piezo resistance caused by deformation of a semiconductor layer due to vibrations of a cantilever, and the second vibration detecting portion as an acoustic vibration detecting portion for measuring a change in parameters of an equivalent circuit of a depletion layer. The present invention is, however, not limited to the combination of these micro-vibration detecting portion and acoustic vibration detecting portion. A variety of combinations

of vibration sensors having various basic structures and operating principles may be applicable insofar as the combination is comprised of a first vibration detecting portion and a second vibration detecting portion having a higher frequency than the first vibration detecting portion and being operated on a different principle from that of the first vibration detecting portion.

[0062] Thus, it will be easily recognized that the present invention encompasses various embodiments not stated herein. Therefore, the technical scope of the present invention is defined only by specifications as the invention according to the scope of claim for patent as appropriate from the foregoing description.

[0063]

[Effects of the Invention] As described above, according to the present invention, a semiconductor vibration sensor having a small size and being capable of simultaneously detecting vibrations having different frequency bands and different vibration levels is provided.

[0064] Moreover, in a case that a first vibration detecting portion and a second vibration detecting portion are integrated on one semiconductor board with high density, micro-vibrations of specific vibration frequency can be detected with high sensitivity such that they are easily separated from vibrations of different frequency band that are background or noise components while preventing mutual interference.

[Brief Description of the Drawings]

[FIG. 1] A top plan view showing a structure of a

semiconductor vibration sensor in accordance with an embodiment of the present invention.

[FIG. 2] A cross-sectional view showing a structure of the semiconductor vibration sensor in accordance with the embodiment of the present invention.

[FIG. 3] A cross-sectional view showing a structure of a package of the semiconductor vibration sensor in accordance with the embodiment of the present invention.

[FIG. 4] A perspective view showing a structure of a cantilever in a micro-vibration detecting portion according to the present invention.

[FIG. 5] A perspective view showing a structure of an acoustic vibration detecting vibrator film according to the present invention.

[FIG. 6] A diagram of an electrically equivalent circuit of the micro-vibration detecting portion according to the present invention.

[FIG. 7] A diagram of an electrically equivalent circuit of the acoustic vibration detecting portion according to the present invention.

[FIG. 8] A system diagram of a transmitter portion in a monitoring system for human mental/physical conditions and surrounding situations using the semiconductor vibration sensor according to the present invention.

[FIG. 9] A system diagram of a receiver section in the monitoring system for human mental/physical conditions and surrounding situations using the semiconductor vibration sensor according to the present invention.

[FIG. 10] A cross-sectional view showing main steps in a method of making the semiconductor vibration sensor in accordance with the embodiment of the present invention.

[FIG. 11] A cross-sectional view showing main steps in

the method of making the semiconductor vibration sensor in accordance with the embodiment of the present invention.

[FIG. 12] A cross-sectional view showing main steps in the method of making the semiconductor vibration sensor in accordance with the embodiment of the present invention.

[FIG. 13] A cross-sectional view showing a structure of the semiconductor vibration sensor in accordance with Variation 1 of the embodiment of the present invention.

[FIG. 14] A cross-sectional view showing a structure of the semiconductor vibration sensor in accordance with Variation 2 of the embodiment of the present invention.

[FIG. 15] A cross-sectional view showing a structure of the package for the semiconductor vibration sensor in accordance with Variation 2 of the embodiment of the present invention.

[Explanation of Reference Symbols]

2a – 2l Bonding pad

3 Vibrator film

4 Cantilever

5 Si substrate

6 Constant current source and amplifying circuit

7 I-to-V converter

8 Buried p^+-layer

9 Buried-layer extracting electrode

10 Element separator area

11 Acoustic vibration (sound wave) detecting portion (Second vibration detecting portion)

12 Micro-vibration detecting portion (First vibration detecting portion)

13 Schottky electrode

14 Depletion layer

15 P^+-sinker

16 P-well

17 Contact area

18 Passivation film

19, 20 Piezoelectrode

23, 24 Packaging case

25 Sound wave inlet port

26 Lead

27 Equivalent circuit of the acoustic sensor

28 Output voltage

29 Output voltage

30 Operational amplifier circuit

31 Adder

32 Modulator

33 Antenna

34 Receiver section

35 Demodulator

36 FFT

37 Frequency spectrum analyzer

38 Knowledge database

39 Display section

40 – 42, 45 – 50 Resist

43 SiO_2 film

44 Si_3N_4 film

52 Cantilever

53 P-well

54 Pit

55 Micro-vibration detecting portion

56, 57 Packaging case

58 Drain electrode

59 Source electrode

60 Gate electrode

61 Polysilicon

SYMBOLS

(FIG. 1)

2a Bonding pad

3 Vibrator film

4a, 4b, 4c Cantilever

5 Si substrate

6a, 6b, 6c Constant current source and amplifying circuit

7 I-to-V converter

8 Buried p^+-layer

9 Buried-layer extracting electrode

10 Element separator area

(FIGS. 2, 14)

3 Vibrator film

4b, 52(FIG. 14) Cantilever

5 Si substrate

8 Buried p^+-layer

9 Buried-layer extracting electrode

10 Element separator area

11 Acoustic vibration (sound wave) detecting portion

12, 55(FIG. 14) Micro-vibration detecting portion

13 Schottky electrode

14 Depletion layer

15 P^+-sinker

16, 53(FIG. 14) P-well

17a, 17b Contact area

18 Passivation film

19, 20 Piezoelectrode

54(FIG. 14) Pit

(FIGS. 3, 15)

2 Bonding pad

3 Vibrator film

23, 24, & 56, 57(FIG. 15) Packaging case

25 Sound wave inlet port (((((Acoustic vibrations

26 Lead

(FIG. 4)

4 Cantilever

Mass m

(FIG. 5)

8 Buried p^+-layer

13 Schottky electrode

14 Depletion layer

(FIG. 6)

ic Constant current circuit

Rp P-type piezo resistance layer

Amplifier A

28 Output voltage

(FIG. 7)

27 Equivalent circuit for the acoustic sensor

29 Output voltage

30 Operational amplifier circuit

igr Generation-recombination current

C_j Depletion layer capacity

R_j Junction resistance

Rs Series resistance

Rf Feedback resistance

(FIG. 8)

11 Acoustic vibration detecting portion

12a, 12b, 12c Micro-vibration detecting portion

31 Adder

32 Modulator

33 Antenna

A1... Amplifier

(FIG. 9)

34 Receiver section

35 Demodulator

36 FFT

37 Frequency spectrum analyzer

38 Knowledge database

39 Display section

A5 Amplifier

(FIG. 10)

(a) 5 Si substrate

8 Buried p^+-layer

40 Resist

(b) 15 P-well

41 Resist

(c) 15 P^+-sinker

17a, 17b Contact area

42 Resist

(d) 43 SiO_2 film

44 Si_3N_4 film

(e) 10 Element separator area

(FIG. 11)

(a), (b), (c), (d) 45, 46, 47, 48, 49 Resist

(e) 9 Buried-layer extracting electrode

19, 20 Piezoelectrode

(FIG. 12)

(a) 50 Resist

(b) 13 Schottky electrode

14 Depletion layer

43 SiO_2 film

(FIG. 13)

9 Micro-vibration detecting portion

Constant current source and amplifying circuit

50 Source electrode

58 Drain electrode

60 Gate electrode

61 Polysilicon

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